RESEARCH BULLETIN 761 APRIL 1955

The Effect of 2,4-Dichlorophenoxyacetic Acid (2,4-D) on Wheat, Oats, Barley

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THE EFFECT OF 2,4-DICHLOROPHENOXY-ACETIC ACID (2,4-D) ON WHEAT, OATS, BARLEY AND THE LEGUMES UNDERSEEDED IN THESE CROPS

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The discovery of the herbicidal properties of 2,4-dichlorophenoxy-acetic acid (2,4-D) gave impetus to selective chemical weed control research. As the herbicidal properties of 2,4-D became more generally known the need for determining the physiological and morphogenic effects of this chemical on the crop plants became evident.

Studies of the effect of 2,4-D on the small grains have been in progress in Ohio continuously since 1945. However, in the interest of brevity only the 1949 and 1950 results are presented in this paper. Progress reports of these studies have been made previously (4, 20, 21, 22, 23, 24, 25). The purpose of the studies reported herein were: (1) to determine the physiological and morphogenic effects of 2,4-D on wheat, oats and barley; (2) to determine the effect of 2,4-D on the yield, protein content, germination, and milling and baking quality of some of these crops; (3) to determine the effect of 2,4-D on the legumes normally underseeded in small grains and (4) to study the differential responses of several important varieties of wheat and oats to 2,4-D.

REVIEW OF LITERATURE

Preliminary investigations conducted on the effect of 2,4-D on small grains from 1945 to 1948 in Ohio suggested considerable variability in the effects of 2,4-D on small grains depending on the formulation of 2,4-D, rate of application, stage of growth of cereals when treated, varietal differences, and seasonal differences as influenced by environmental factors such as temperature, rainfall, and soil properties (20, 30).

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These results were similar to those being reported by many investigators (3, 7, 8, 10, 11, 13, 14, 15, 26, 28, 29). In addition to the similarity of results being obtained many different results were being reported. In many instances opposite responses with respect to the effect of 2,4-D on yield, germination, protein content, varietal responses and milling and baking quality of small grains were being reported (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 28, 29, 30, 33).

The failure of investigators to obtain similar results throughout such a wide and variable geographical area might have been expected. A review of the literature clearly indicates that some of the reasons for failure to obtain similar results among workers were: (1) the use of different formulations of salts and esters of 2,4-D which varied in selectivity, volatility and total activity, (2) the use of a too narrow range of rates of application that often gave considerable reductions in yield which were found not to be significant because of inadequate experimental designs and high variability in application techniques, (3) the use of too few stages of growth for treatment resulting in treatments only at tolerant or susceptible stages of growth, (4) the use of experimental designs which confounded the effects of weed competition with the effects of 2,4-D, and (5) actual differences associated with different varieties grown under different intensities of insect and disease infestation, and different moisture, temperature, and soil fertility levels, resulting in a different physiological condition of the plants at the time of treatment causing variability in the susceptibility or tolerance of the plants at any given time.

A voluminous literature has developed on the effects of 2,4-D on various small grains. No attempt has been made to review this literature, but some of the directly related work has been cited.

MATERIALS AND METHODS

Thorne wheat was planted October 4, 1948 with a 12-7 grain drill. A split plot design with four replications, in which stages of growth were main plots and rates of an amine salt and a butyl ester formulation of 2,4-D were sub-plots, was used for this study. The sub-plots were 7 × 25 feet with one-foot borders. An amine salt and a butyl ester formulation of 2,4-D at rates of 0, ¼, ½, 1, 2, and 4 pounds acid equivalent per acre were applied at ten stages of growth as indicated in Figure 1.

A similar experiment with wheat was repeated in 1949-1950 in which Butler wheat was planted in three replicates of a split plot design with sub-plots 7 × 17 feet. In order to evaluate fall applications more fully the amine salt formulation was applied at rates of 0, ¼, ½, 1, 2 and 4 pounds, acid equivalent, per acre at fifteen stages of growth as indicated in Figure 6.

Six of the most important wheat varieties in the Ohio wheat breeding program were studied for their response to 2,4-D in a split-split plot experiment with three replications in 1949. The experiment was planted with a 12-7 grain drill and divided into sub-plots 7 × 20 feet. The varieties were treated in the 3 leaf stage, November 6; when fully tillered, April 20; and in the late joint or boot stage, May 4 with 0, ½, 1, 2, and 4 pounds, acid equivalent, per acre of 2,4-D as the butyl ester, as indicated in Figure 10.

Clinton 59 oats was planted April 14, 1949 with a 18-7 grain drill. A split plot design with four replications in which stages of growth were main plots, and rates of the amine salt and the butyl ester formulations of 2,4-D were sub-plots was used for this study. The sub-plots were 10 × 20 feet with one foot borders. An amine salt and a butyl ester formulation of 2,4-D at acid equivalent rates of 0, ¼, ½, 1, 2 and 4 pounds per acre were applied at nine stages of growth as indicated in Figure 7.

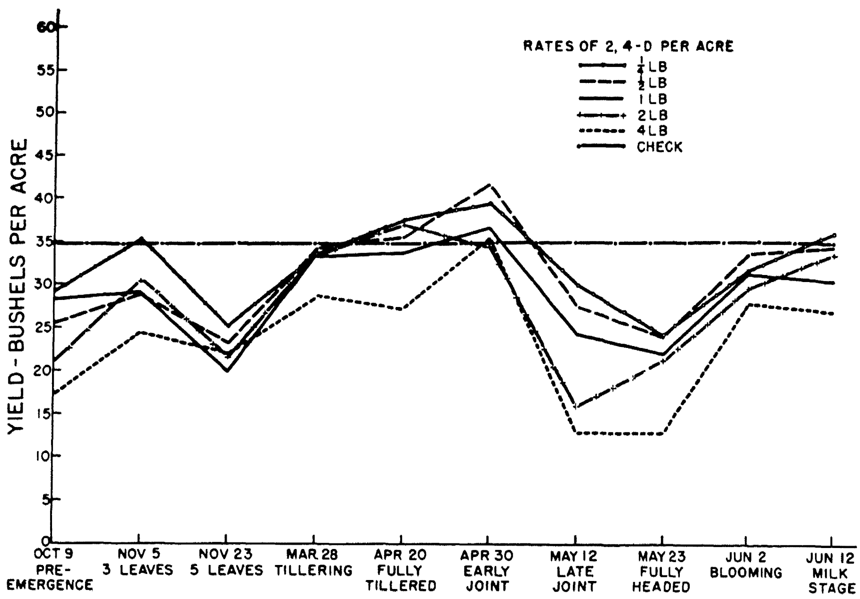

Fig. 1.—The effect of 2,4-D on the yield of Thorne wheat. Average of amine and ester formulations, 1948-1949.

A similar experiment was conducted in 1950 in which Clinton 59 oats was planted in a split-split plot design with sub-plots 6 × 21 feet replicated three times. The isopropyl ester of 2,4-D was applied at acid equivalent rates of 0, ¼, ½, 1, 2 and 4 pounds per acre at nine stages of growth as indicated in Figure 9.

Fourteen of the most important oat varieties in the Ohio oat breeding program were studied for their response to 2,4-D in 1948. From these studies, Columbia, Ajax, Clinton and Mindo were selected for further study in 1949. The experimental procedure was similar to that used in the wheat variety response studies.

Winter barley was planted in 1947 with a 18-7 grain drill. A randomized block design with three replications was used. The plots were 10 × 70 feet with one foot borders. An amine salt and a butyl ester of 2,4-D at acid equivalent rates of 0, ¼, ½, ¾, and 1 pound per acre were applied at the five leaf stage, full tiller stage, 2-joint or boot stage and the full bloom stage and the effects of 2,4-D on yield, protein content and germination were determined.

The effect of 2,4-D on the germination of grain harvested from field treated small grains was determined by placing samples in a germinator for seven days. If the seedlings measured less than two inches from shoot-tip to root-tip after seven days they were recorded as weak germinators. If the seedlings measured two inches or more they were recorded as strong germinators. If they failed to germinate in seven days they were assumed to be dead.

The effect of 2,4-D on the protein content of small grains was determined by methods adopted by the U.S.D.A. Soft Wheat Laboratory at Wooster, Ohio (4).[2] Duplicate determinations which checked within 0.2 percent protein were made on each sample from each plot. Percent nitrogen was converted to wheat protein using the factor 5.7. Wheat protein as obtained was then converted to wheat protein on a 14 percent moisture basis.

In order to determine the effect of 2,4-D on the milling and baking quality of flour from grain harvested from previously treated wheat, samples of wheat produced in the experiment presented in Figures 1 to 4 were taken from the most tolerant stage of growth and one of the most susceptible stages as indicated in Table 1. Methods adopted by the U. S. Department of Agriculture Soft Wheat Laboratory at Wooster, Ohio were used to determine the effect of 2,4-D on milling and baking quality of wheat (4).

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[2]The authors wish to acknowledge the assistance of C. E. Bode and his staff at the U. S. Department of Agriculture Soft Wheat Laboratory at Wooster, Ohio in carrying out the protein determinations and milling and baking studies.

The effects of 2,4-D, applied at various stages of growth of small grains, on stands of legumes underseeded in these crops were determined in the wheat and oat studies. In addition the effect of 2,4-D on yields in 1951 of a red clover-alfalfa mixture sown in 1950 in oats treated with 2,4-D was determined.

Except as indicated all studies were conducted on small grains essentially free of weeds. All rates of 2,4-D are expressed on an acid equivalent basis and all applications were made with an experimental plot sprayer delivering 10 gallons of solution per acre at a speed of 4 mph and a pressure of 30 psi (19).

RESULTS AND DISCUSSION

THE EFFECTS OF 2,4-D ON WHEAT

The effects of 2,4-D on the yield, protein content, protein yield per acre, and the germination and milling quality of the grain and the baking quality of flour from Thorne wheat previously treated with 2,4-D in 1948-49 are shown in Figures 1, 2, 3, 4, and 5, and Tables 1 and 2. The yield of Butler wheat treated at 15 stages in 1949-50 is given in Figure 6. The yield response of six important wheat varieties treated at different stages of growth with 2,4-D is presented in Figure 10.

The analysis of variance of the 1948-49 data indicated that stages of growth, rates of application and the interactions of rates $\times$ stages of growth, and stages of growth $\times$ formulations were highly significant for yield, protein content and protein per acre. In addition the F value for formulations of 2,4-D for protein content was significant, although that for yield of grain or protein per acre was not. This indicates that protein content was a more sensitive measure of 2,4-D injury than yield.

Effect on Yield.—The data indicate that the yield of Thorne wheat was reduced by 2,4-D applied at any time from emergence to tillering and again just prior to heading (Figures 1, 2, 3, 4, 5 and 6). Fall applications generally reduced yields but not as seriously as treatments just prior to blooming. The full tiller and milk stages were clearly the most tolerant stages. In 1948-1949 a sharp reduction in yield occurred at the five leaf stage and again at the late joint and fully headed stages, while in 1949-1950 the fall treatments resulted in general yield reductions but the sharp reduction obtained at the five leaf stage in the previous year was not found. In 1949-1950 the most sensitive stage in the spring was well defined as the "boot" stage compared with two sensitive stages in 1948-1949, one occurring just prior to the "boot"

TABLE 1.—The effect of 2,4-D treatments on the milling and baking quality of flour from Thorne wheat

Rate 2,4-D per acre	Yield wheat per acre	Wheat: Ash*	Wheat: Protein*	Wheat: Flour yield	Flour: Ash*	Flour: Protein*	Mixogram area: Uncorr.	Mixogram area: Corr. to 9 % prot.	Cookie baking: Diam.	Cookie baking: Top grain
Lb.	Bu.	Pct.	Pct.	Pct.	Pct.	Pct.	Cm^2	Cm^2	Cm. × 2	Rating
				Amine salt applied at full tiller stage (Most tolerant stage)						
0	34.6	1.79	10.5	62.0	.46	9.2	63	62	18.6	S
¼	34.1	1.86	10.7	63.9	.46	9.3	63	61	18.7	S
½	36.3	1.81	10.7	63.3	.49	9.4	63	60	18.7	S
1	33.4	1.83	10.8	63.4	.46	9.6	66	62	18.7	S
2	35.1	1.82	10.9	62.2	.45	9.5	63	59	18.6	S
4	31.1	1.87	11.8	64.2	.50	10.6	72	61	18.3	S
				Butyl ester applied at full tiller stage (Most tolerant stage)						
0	36.8	1.76	10.5	63.5	.47	9.1	68	67	18.8	S
¼	40.0	1.80	10.9	61.4	.47	9.4	69	66	18.5	S
½	33.8	1.79	10.8	62.0	.45	9.2	66	65	18.7	S
1	33.5	1.92	11.7	63.3	.49	10.4	75	65	18.5	S
2	36.8	1.86	11.8	60.8	.48	10.5	76	65	18.6	S
4	27.2	1.86	11.4	61.8	.47	10.0	70	63	18.8	S
				Amine salt applied at fully headed stage (Very susceptible to injury)						
0	31.4	1.85	10.6	63.7	.48	9.0	61	61	18.5	S
¼	24.9	1.81	10.9	61.8	.43	9.4	65	62	18.4	S
½	22.2	1.83	11.3	63.1	.48	10.0	69	62	18.6	S
1	23.7	1.85	11.8	63.3	.49	10.2	73	65	18.3	S
2	28.8	1.82	11.5	63.6	.48	10.1	70	62	18.4	S
4	17.7	1.91	14.6	62.8	.53	12.8	87	60	18.0	S-Q†
				Butyl ester at fully headed stage (Very susceptible to injury)						
0	33.8	1.78	10.3	63.7	.46	9.0	60	60	18.6	S
¼	23.7	1.84	11.7	63.2	.48	10.1	70	62	18.6	S
½	25.7	1.86	11.7	63.5	.49	10.1	69	61	18.7	S
1	19.9	1.85	13.5	64.4	.52	11.7	81	62	18.5	S
2	13.5	1.87	14.5	62.5	.53	12.7	85	59	18.3	S
4	8.4	1.95	16.5	60.6	.54	14.5	94	55	17.7	Q-U‡

*Corrected to 14 % moisture.
†Cookie quality questionable.
‡Cookie quality unsatisfactory.

stage and the second immediately after. These differences indicate that the most sensitive stage in each instance is rather short. In 1948 the most sensitive fall stage was clearly found, but it was "bracketed" in 1949. In 1950 the most sensitive "boot" stage was clearly found but it was bracketed in 1949. These data strongly indicate the risks involved in attempting to use 2,4-D in small grains at stages other than those known to be tolerant.

Effect on Protein Content and Protein Yield per Acre.—The effect of 2,4-D on the protein content and protein yield per acre in grain harvested following treatment of Thorne wheat with an amine salt and a butyl ester formulation of 2,4-D at six rates of application and ten stages of growth is indicated in Figures 3, 4 and 5. In general, when the mean yield, protein content and protein yield per acre for both formulations at all rates of application at ten stages of growth are compared, protein content varied inversely with yield.

The slight increases in yield of grain and yield of protein per acre in the grain at the fully tillered and early joint stages are attributed to spot infestations of Canada thistle that occurred in otherwise weed free

TABLE 2.—The effect of 2,4-D on the germination of Thorne wheat harvested after treatment with the butyl ester and amine salt of 2,4-D at 0, ¼, ½, 2, 4 pounds of 2,4-D per acre

Columbus, Ohio, 1948-1949

Stage of growth		Average of both formulations at all rates of application		
		Strong*	Weak*	Dead*
Oct. 9	Pre-emergence	97	1	2
Nov. 5	3 leaves	99	0	1
Nov. 23	5 leaves	96	2	2
Mar. 28	Tillering	98	1	1
Apr. 20	Fully tillered	98	1	1
Apr. 30	Early joint	98	1	1
May 12	Late joint	93	3	4
May 23	Fully headed	97	2	1
June 2	Blooming	91	8	1
June 12	Milk stage	98	1	1
Untreated check plots (av. of 80)		98	1	1

*Strong refers to those seedlings measuring 2 inches or more after seven days in the germinator; weak to those less than 2 inches long; dead to those not germinating in seven days.

wheat. These slight increases in yield were not statistically significant. Protein content was a more precise index of the effect of 2,4-D on wheat than yield.

Effect on Germination.—The effect of 2,4-D on the germination of wheat is shown in Table 2. The data show that seed viability was not reduced by applications of either formulation of 2,4-D at any of the rates of application or stages of growth with the possible exception of the late joint stage. However, when 2,4-D was applied at the bloom stage an appreciable reduction in the strong and a corresponding increase in the weak germinating seeds occurred, but seed viability was not affected.

Effect on Milling and Baking Quality.—The effect of 2,4-D on the milling and baking quality of Thorne wheat is shown in Table 1. These studies were conducted using samples from the full tiller and fully headed stages of growth on the assumption that these stages were among the most tolerant and most susceptible stages respectively in the response of wheat to 2,4-D (Figure 1).

These data indicate that the milling and baking quality of wheat was not affected by 2,4-D treatment except when the chemical was applied at high rates of application and susceptible stages of growth.

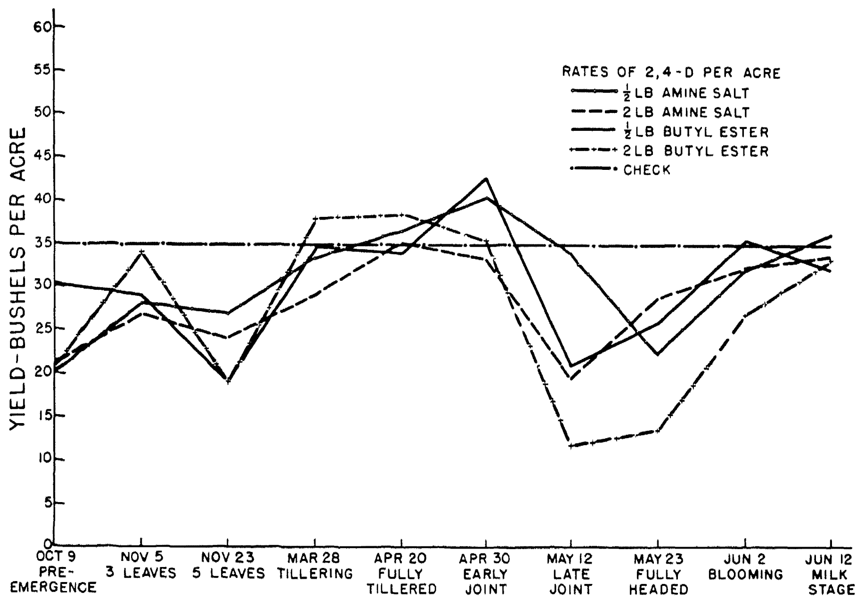

Fig. 2.—The effect of an amine salt and butyl ester of 2,4-D on the yield of Thorne wheat, 1948-1949.

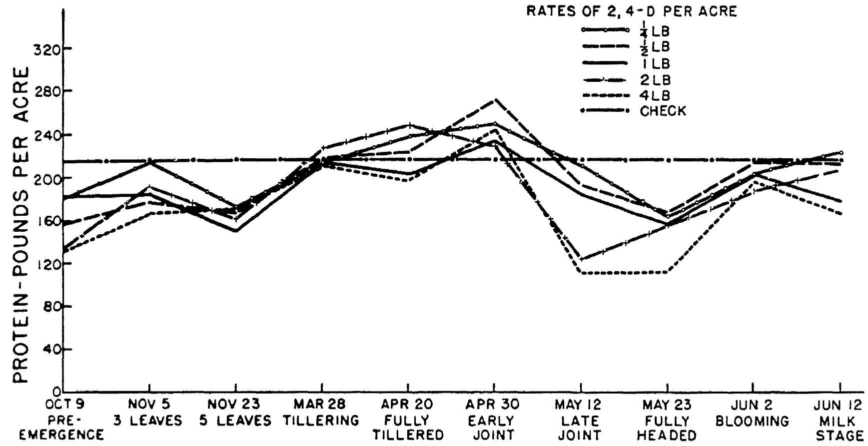

Fig. 3.—The effect of 2,4-D on the protein yield of Thorne wheat per acre. Average of amine and ester formulations, 1948-1949.

The data in Table 1 clearly indicate that the butyl ester of 2,4-D at 4 pounds acid equivalent per acre applied at the fully headed stage decreased yield, increased ash and protein content and decreased the flour yield of wheat; increased the ash and protein content of flour, increased the uncorrected mixogram area, decreased the corrected mixogram ara and rsultd in unsatisfactory cookie baking quality. The effect of the amine salt of 2,4-D at this stage on the milling and baking quality of wheat was similar but less severe.

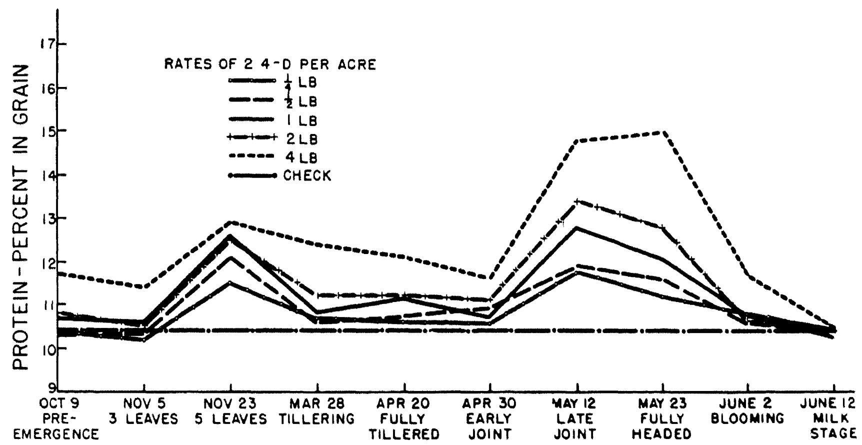

Fig. 4.—The effect of 2,4-D on the protein content of Thorne wheat. Average of amine and ester formulations, 1948-1949.

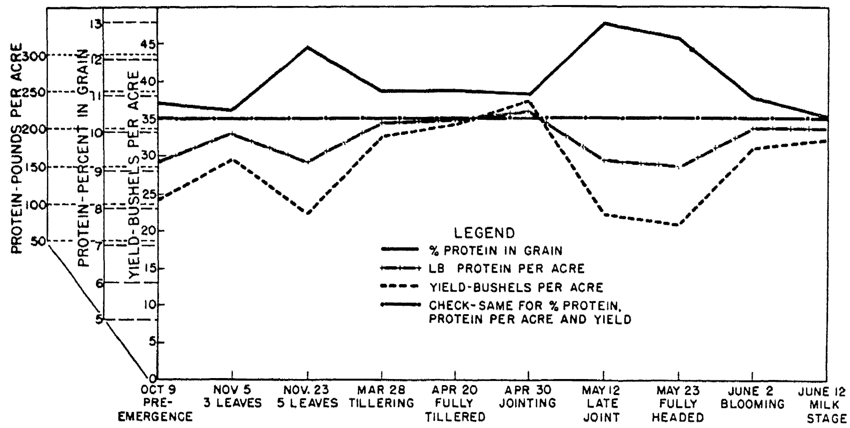

Fig. 5.—The effect of 2,4-D on the protein content, protein per acre, and yield of Thorne wheat. Average of all rates of amine and ester formulations, 1948-1949.

THE EFFECTS OF 2,4-D ON OATS

Effect on Yield.—The effect in 1949 of an amine salt and a butyl ester of 2,4-D on Clinton 59 oats when applied at six rates of application and nine stages of growth is summarized in Figure 7. The analysis of variance indicated significant differences between stages of growth, rates

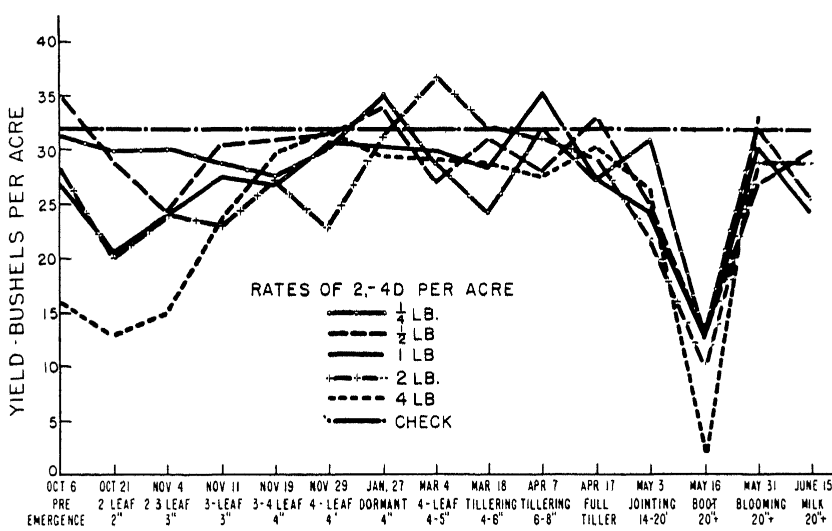

Fig. 6.—The effect of an amine salt of 2,4-D on the yield of Butler wheat, 1949-1950.

of application, formulations of 2,4-D, and the interactions of rates × formulations, rates × stages of growth, stages × formulations, and stages × rates × formulations. Similar results were obtained with the same rates of the isopropyl ester of 2,4-D in 1950 (Figure 9).

Oats were much more sensitive to injury from 2,4-D than barley or wheat. However, the pre-tiller stage and boot and early heading stages were clearly defined as the least tolerant stages while the full tiller and blooming and milk stages were the most tolerant stages in the life cycle response of oats to 2,4-D.

Effect on Protein Content, Yield of Protein per Acre, and Germination.—The effect of 2,4-D on the protein content and protein yield per acre of oats was similar to that reported for wheat. Protein content was inversely related to yield. All treatments which resulted in decreased yields resulted in increased protein content of grain and a decrease in total protein per acre.

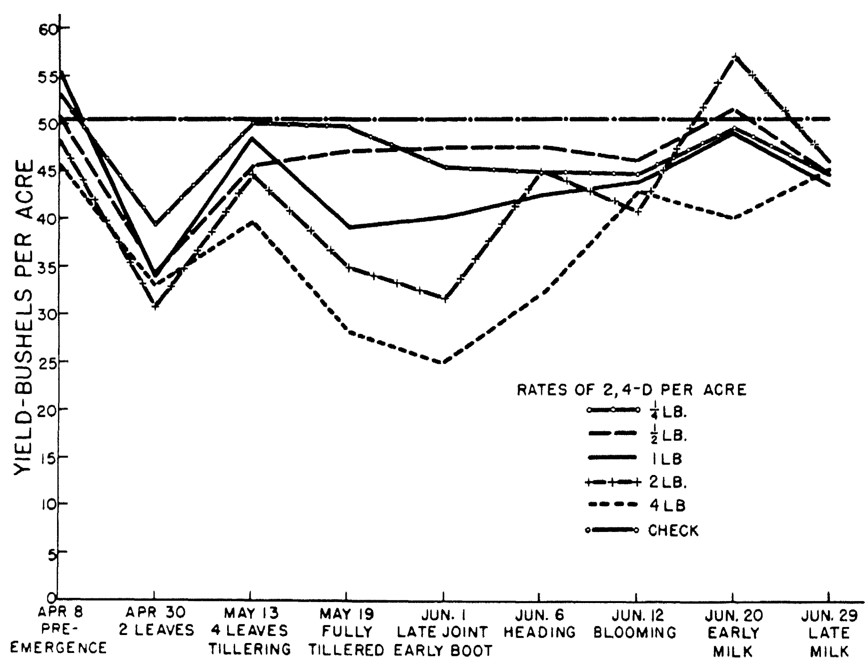

Fig. 7.—The effect of 2,4-D on the yield of Clinton oats. Average of amine and ester formulations, 1949.

TABLE 3.—The effect of 2,4-D on the germination of Clinton 59 oats harvested after treatment with the butyl ester and amine salt of 2,4-D at 0, 1/4, 1/2, 1, 2 and 4 pounds of 2,4-D per acre

Columbus, Ohio, 1949

Stage of growth	Average of both formulations at all rates of application		
	Strong*	Weak*	Dead*
Apr. 8 Pre-emergence	91	2	7
Apr. 30 2 leaves	95	1	4
May 13 4 leaves	86	2	12
May 19 Jointing	82	2	16
June 1 Early boot	74	3	23
June 6 Heading	88	2	10
June 12 Blooming	83	2	15
June 20 Early milk	88	2	10
June 29 Late milk	89	1	10
Av. all rates and stages:			
Amine salt	88	2	10
Butyl ester	85	2	13
Untreated check plots (av. of 72)	92	2	6

*Strong refers to those seedlings measuring 2 inches or more after seven days in the germinator; weak to those less than 2 inches long; dead to those not germinating in seven days.

Highly significant reductions in seed viability resulted from all applications of 2,4-D in all stages of growth except the pre-emergence and 2-leaf stages of growth (Table 3). These results suggest that 2,4-D applied to the foliage was absorbed and translocated to the seeds. Research now in progress using chemical and Warburg respiration techniques indicate that 2,4-D or its stimulus or a decomposition product producing an effect similar to 2,4-D was found in oat and wheat seed harvested after the parent plants had been treated (27, 34).

THE EFFECTS OF 2,4-D ON BARLEY

The mean yield, protein content and germination of barley after treatment with an amine salt and a butyl ester formulation of 2,4-D at four stages of growth are shown in Table 4. There were no significant differences between formulations or stages of growth. However increasing the rate of application reduced yields significantly. The treatments studied did not have any significant effect on the protein content or germination of the grain. These results on the effect of 2,4-D on barley are typical of those referred to in the literature review in which a too narrow range of rates of application and too few growth stages were studied.

TABLE 4.—The effect of 2,4-D on winter barley,* 1947-48

2,4-D per acre	Yield per acre	Protein in grain	Germination		
			Strong†	Weak	Dead
lb.	bu.	pct.	pct.	pct.	pct.
0	65.9	9.7	97	3	0
1/4	65.0	9.5	97	3	0
1/2	65.0	9.8	97	2	1
3/4	62.1	10.1	96	3	1
1	61.1	9.9	97	3	0

*The data are means of amine and butyl ester formulations applied at four stages of growth (five-leaf stage, full tiller, early boot, and full bloom).

†Same evaluation used as for wheat and oats.

VARIETAL RESPONSES

The yield responses of six varieties of wheat to the butyl ester formulation of 2,4-D at acid equivalent rates of 0, 1/2, 1, 2, and 4 pounds per acre applied at two sensitive stages and one tolerant stage of

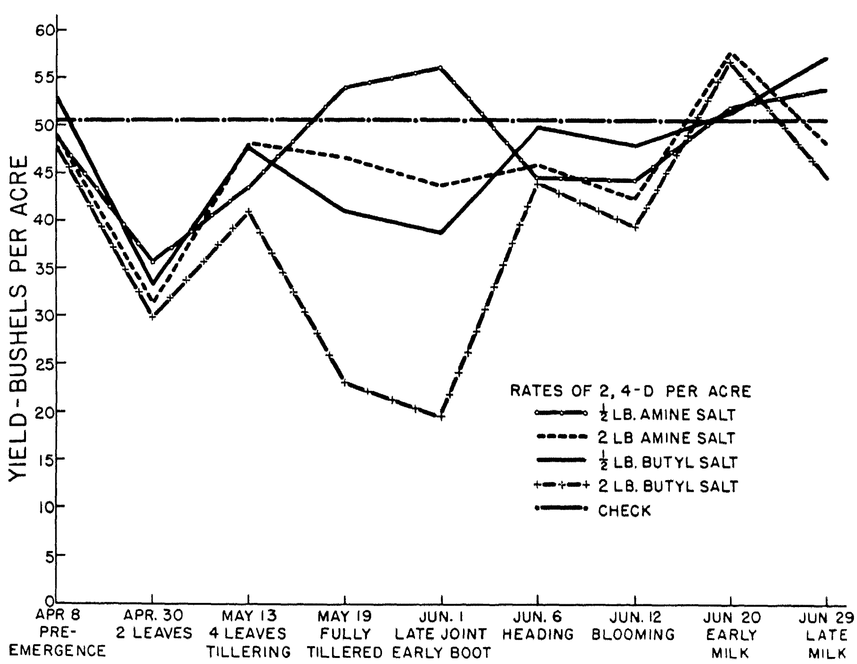

Fig. 8.—The effect of amine salt and butyl ester of 2,4-D on the yield of Clinton oats, 1949.

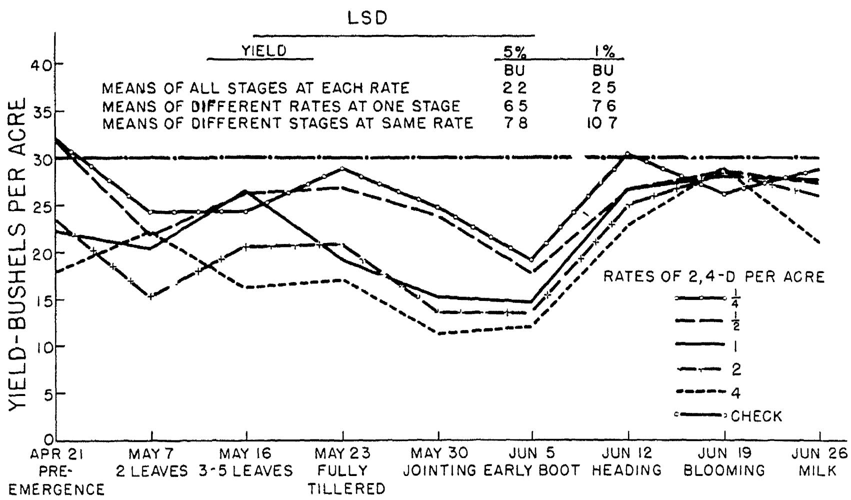

Fig. 9.—The effect of an isopropyl ester of 2,4-D on the yield of Clinton 59 oats, 1950.

growth are shown in Figure 10. On the basis of mean relative yields (average of untreated checks=100) for all rates and all stages the six varieties may be ranked, the most tolerant first, as follows: TN 1016-4,

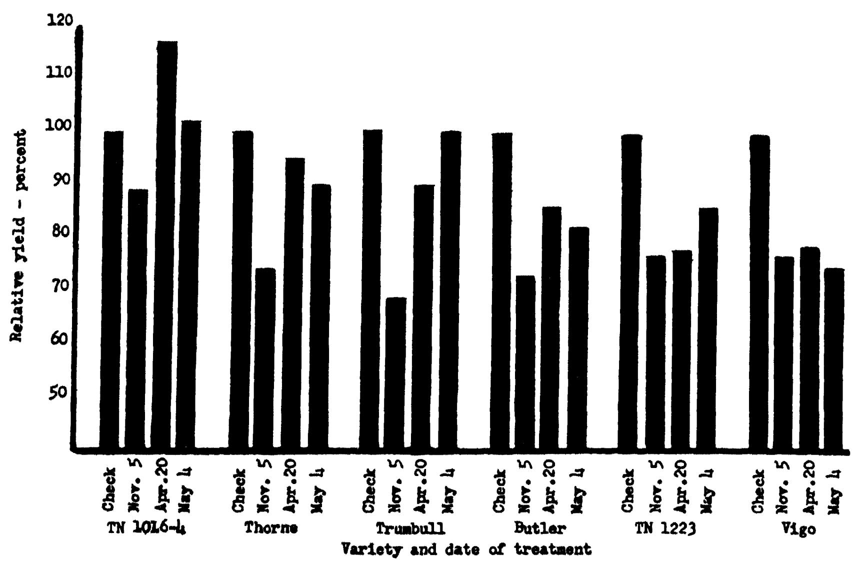

Fig. 10.—The relative yield of six varieties of soft red winter wheat when treated at three stages of growth. Yields are the average of all rates of 2,4-D applied.

103; Thorne, 87; Trumbull, 86; Butler, 81; TN 1223, 80; and Vigo, 77: however, a significant stage × variety interaction is evident in Figure 10. The protein content of each variety as affected by 2,4-D treatment was also determined. Without exception protein content was inversely related to yield and the most sensitive varieties showed the greatest increases in protein content following 2,4-D treatments that reduced yield.

Four oat varieties were selected in 1949 from fourteen varieties which had been investigated for their responses to 2,4-D in 1948. The four varieties were treated with the butyl ester of 2,4-D at acid equivalent rates of 0, ½, 1, 2, and 4 pounds per acre at the two leaf, full tiller and late boot stages of growth. On the basis of mean relative yields (check=100) for all rates and all stages the four varieties ranked, the most tolerant first, as follows: Columbia, 76; Ajax, 70; Clinton, 64; and Mindo, 53. A significant rate × stage × variety interaction was also evident in the oat variety study.

THE EFFECT OF STAGE OF GROWTH ON RESPONSE OF SMALL GRAINS TO 2,4-D

The data from these studies strongly indicate that stage of growth was one of the most important factors affecting the response of small grains to 2,4-D. The interactions of stages × rates and stages × formulations were highly significant in all experiments (Figures 2 and 7). In these studies a statistically significant difference in yield due to formulations was evident in the oat experiments but not in the wheat experiments.

As might be expected, there was some variation in response within stages for different years. However, it appears from these studies that the physiological condition of the plant as expressed in rate of growth at the exact time of treatment within a given morphological stage of growth is the important factor in accounting for the variable responses encountered. Responses associated with different years appeared to be an expression of the physiological condition of the plant associated with environmental conditions affecting plant growth. Investigations by other workers in which 2,4-D was applied at 3-day intervals on wheat and barley support the conclusions above (16).

MORPHOGENIC RESPONSES

The application of 2,4-D to wheat, oats and barley resulted in many morphogenic responses including leaf rolling, a more erect habit of growth, reduced number of tillers per plant (Figure 11), failure of heads to emerge from the boot, lateral emergence of heads through tightly rolled terminal tissue (Figure 12), reduced plant height, a variable number of kernels per head, and delayed maturity.

EFFECT OF 2,4-D ON LEGUMES UNDERSEEDED IN SMALL GRAINS

Studies were conducted on the effect of 2,4-D on the stand of legumes underseeded in wheat and oats in 1947, 1948, 1949, and 1950. A mixture of alfalfa, red clover and Ladino clover was sown in the small grain experiments in 1947, 1948 and 1949, and a mixture of alfalfa and red clover in 1950.

Excellent stands of all legumes were obtained when spring seedings followed fall applications of 2,4-D regardless of rate or formulation. Rates of 4 pounds of 2,4-D per acre applied in the fall showed no

Fig. 11.—Foreground and left and right untreated. From front to back, plots treated with 2, 1, and ½ pound of 2,4-D as the butyl ester applied in the 2-leaf stage showing inhibited tiller production and inhibited growth of wheat.

residual effect on legume seedings made in March. All rates of both formulations of 2,4-D applied at any time after the legumes emerged resulted in a partial to complete kill of alfalfa, red clover and Ladino clover. The degree of stand reduction was influenced by rate and

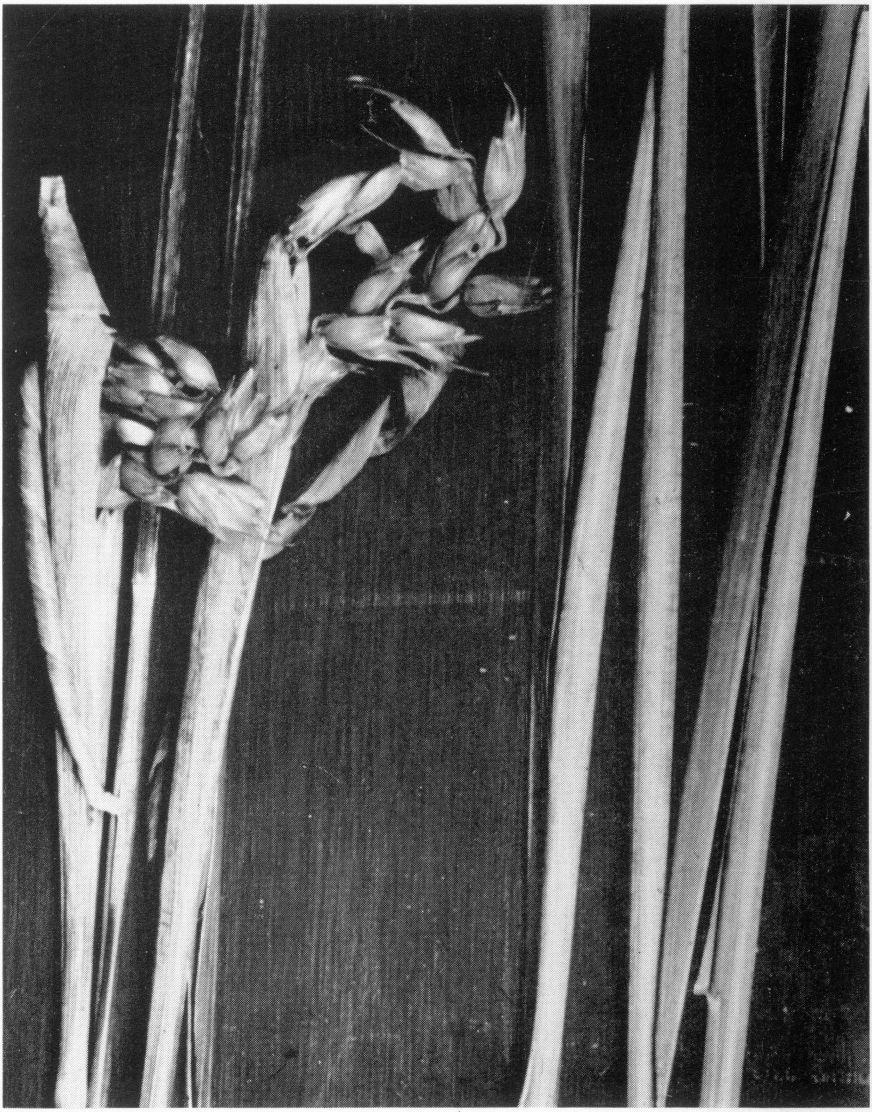

Fig. 12.—Left, lateral emergence of heads of wheat from the boot produced by 1/4 pound of 2,4-D applied in the five-leaf stage in the fall. Right, untreated plants.

TABLE 5.—The effect of an isopropyl ester of 2,4-D on the stand and yield of a mixture of red clover and alfalfa seeded in oats in 1950 and harvested in 1951

Date of treatment	Stage of growth of oats	Stand rating* in 1950 and yield per acre in 1951 after treating with the following acid tquivalent rates of 2,4-D:												Average yield all treated plots each stage
		0 lb.		¼ lb.		½ lb.		1 lb.		2 ib.		4 lb.		
		Stand	Yield Lb.	Stand	Yield Lb.	Stand	Yield Lb.	Stand	Yield Lb.	Stand	Yield Lb.	Stand	Yield Lb.	Lb.
Apr. 21	Pre-emergence	10	5100	7	5250	3	4430	3	3820	1	2000	1	1600	3520
May 7	2 leaves, 2″	10	5450	6	5060	6	4600	3	1620	0	1130	1	370	2560
May 16	3-5 leaves 6-8″	10	5360	8	5120	6	4530	1	2360	0	430	0	240	2540
May 23	Fully tillered	10	5390	9	5580	9	5440	1	3260	1	3880	0	360	3700
May 30	Jointing, 12-14″	10	5400	7	5350	9	5130	2	3310	1	1560	0	640	3200
June 5	Early boot	10	4410	7	4270	6	4910	2	3540	7	2780	0	640	3230
June 12	Heading	10	5610	5	5030	5	5170	3	4600	1	1230	0	1020	3410
June 19	Blooming	10	5210	6	4920	6	4890	5	5040	2	3640	2	2700	3720
June 26	Milk	10	5240	9	4840	6	4720	4	4790	2	3730	1	3650	4220
Average all stages		10	5170		5050		4870		3590		2260		1250	

*10—No reduction in stand; 9-8-7, slight reduction; 6-5-4, moderate reduction; 3-2-1, severe reduction in stand; 0, stand essentially eliminated.

formulation of 2,4-D, time of application, and legume mixture. The data in Table 5 indicate that high yields of forage legumes may be obtained following moderate to severe stand reductions by applications of 2,4-D. Many investigations have shown little correlation between stands and yields of forage crops within wide limits of rates of seeding (31, 32). Excellent yields were obtained following treatment with 1/4 pound 2,4-D per acre at all stages of growth of oats in 1950 even though slight to moderate stand reductions occurred (Table 5). It is also obvious from these data that as the oat canopy developed it partially protected the legumes from the 2,4-D treatments applied when oats were in the early boot, heading, blooming, and milk stages. The masking effect of the oat canopy and increased tolerance of the legumes with age at least partially explain the high forage yields of alfalfa and red clover following the application of 2,4-D at one pound per acre in the heading, blooming and milk stages of growth. The order of tolerance of the legumes to 2,4-D, the most tolerant first, was: Ladino clover, red clover, alfalfa.

These studies indicate that 2,4-D may be used for weed control in small grains without serious reduction in forage yields when applied at low rates at stages of growth when the small grain canopy masks the legumes. However, the stand reductions that occurred indicate the degree of risk involved and emphasize the need for phenoxyacetic acid derivatives or other herbicides with greater selectivity and greater safety margins for weed control in small grains underseeded with legumes.

SUMMARY

The responses of wheat, oats, and barley to 2,4-D throughout their life cycles and the effect of this herbicide on yield, protein content, and germination of grain are reported. The differential varietal response of several wheat and oat varieties to 2,4-D, the effect of this chemical on the milling and baking quality of wheat, and the effect of 2,4-D on legumes underseeded in the small grains were also investigated.

These studies may be summarized as follows:

1. Wheat, oats and barley were most tolerant to 2,4-D after the plants were well tillered but before two joints (nodes) of the stem were visible above the rosette and again after the plants had bloomed until harvest. The most susceptible periods in the life cycle of these cereals were the seedling stages prior to the appearance of tillers and again after the second node of the stem appeared until after bloom.

2. The first susceptible stage appeared to be associated with the rapid development of the plants at the time of tiller primordia and floret initiation, while the second susceptible period occurred during the period of rapid floret development. Both susceptible periods are associated with rapid meristematic growth.

3. When 2,4-D was applied at rates normally used for weed control in small grains to weed-free wheat, oats and barley at the most tolerant stages of growth no significant injurious effects were recorded. However, when 2,4-D was applied to wheat, oats and barley at susceptible stages of growth, yield was reduced, protein content was increased, germination percentage of oats was reduced, and germination vigor of wheat was reduced. The germination of barley was not affected by the (lower) rates of 2,4-D applied. In addition, 2,4-D applied at high rates at susceptible stages of growth impaired the milling and baking quality of wheat.

4. A number of morphogenic responses resulted from 2,4-D treatment, including leaf rolling, lateral emergence of the heads from the boot, a reduction in tiller formation, a more erect habit of growth and delayed maturity. These abnormalities occurred only at susceptible stages of growth.

5. The butyl ester formulation of 2,4-D when compared with acid equivalent rates of the amine salt formulation was more phytotoxic and resulted in greater injury to the small grains. These differences were more evident on oats than on wheat or barley.

6. Legume stand reductions usually occurred following the treatment of underseeded small grains with 2,4-D, but reductions in stand were not always associated with reductions in forage yields. However, the risk involved emphasizes the need for an intensified investigation of the phenoxyacetic acid derivatives and other herbicides in order to obtain chemicals with more selectivity and greater safety margins for weed control in small grains underseeded with legumes.

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